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Climatological Variability in Modeling of Long-Term Regional Transport and Deposition of Air Pollutants

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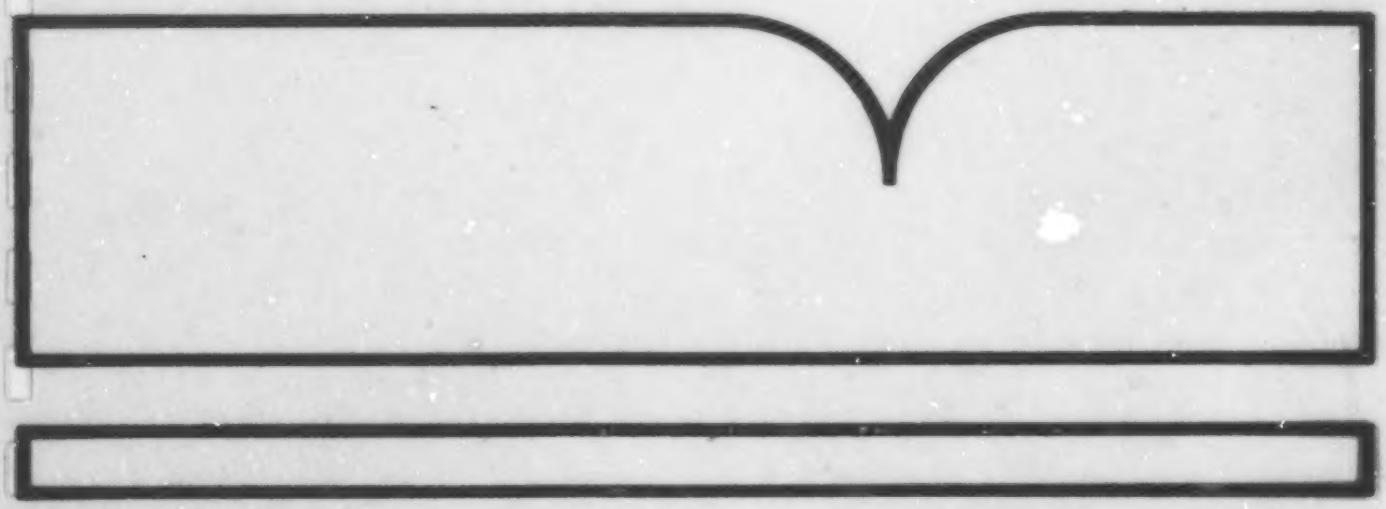

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16. ABSTRACT

Annual variability in sulfur deposition source-receptor matrices due to the variability in the meteorological parameters is investigated. Complete sets of 1980 and 1981 meteorological data and the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) Model are used to produce the annual 11-source, 9-receptor matrices. These annual matrices are compared to the 1978 U.S./Canadian Memorandum of Intent matrices.

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CLIMATOLOGICAL VARIABILITY IN MODELING OF LONG-TERM REGIONAL TRANSPORT AND DEPOSITION OF AIR POLLUTANTS

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In a growing number of emission policy analyses, regulatory proceedings, and cost/benefit assessments, numerical models of long-range transport and deposition of air pollutants have been exercised to estimate source-receptor (S-R) relationships—for the particular meteorological conditions input to the model. The representativeness of the meteorological conditions, or the variability of the model estimates with climatological input from different years or corresponding seasons from different years, is seldom evaluated.

For ultimate users of deposition or air concentration estimates, the form of computation normally most convenient is an S-R transfer matrix, which provides the calculated contribution of each of a number of source regions to each of several receptor regions; examples appeared in studies related to the United States-Canada Memorandum of Intent (MOI) on Transboundary Air Pollution (e.g., Perguson and Machta, 1982). Since the MOI reports received widespread distribution and interest, the S-R matrices in the reports have been applied in a number of policy analyses, such as that of Goklany (1983).

It is well known that models of transport and deposition contain considerable uncertainty, due to lack of critical experimental knowledge and to necessary simplification of complex physical processes for model practicality. An additional uncertainty, however, results from the fact that models must be exercised with past meteorological data, while analysts apply the results to examine potential future policies.

Table I: Source Regions.

Region	
1	Atlantic Provinces
2	Quebec
3	Ontario
4	Manitoba and Saskatchewan
5	New England and New York
6	Ohio, Pennsylvania, and West Virginia
7	Mid-Atlantic (NJ, MD, DE, DC, VA, NC)
8	Deep South (SC, GA, FL, AL, MS, AR, LA)
9	Western Midwest (IN, IL, MO, KY, TN)
10	North Central (MI, WI, MN, IA)
11	Great Plains (TX, OK, KS, NE, SD, and ND)
12	Western U.S. and Canada
13	48 contiguous states and 10 provinces

Many of the developers of the eight state-of-the-science models in the MOI studies utilized only two or four months of meteorological data from 1978 to produce their estimates, as longer sequences of data in model-compatible form were not available at the time. If the meteorological conditions were atypical, S-R results could be misleading in selection of the most effective strategies to reduce acid deposition.

Here, two full years (1980 and 1981) of meteorological data, as well as data from January and July of 1978, are used in the Advanced Statistical Trajectory Regional Air Pollution (ASTRAP) model (Shannon, 1981), one of the eight MOI models, to estimate deposition for the S-R matrix combination of eleven source regions and nine receptors used in the MOI reports. (S-R matrices of dimensions 40 by 9 were also examined in the MOI reports.) Improvements in the ASTRAP model and in the emission inventory since the earlier work require recalculation of the two-month 1978 simulation in order for the comparison to isolate the effect of meteorological variability. The source regions are listed in Table I and the receptor regions are provided in Table II. For completeness, an additional source region, the western states and provinces, has been added, as well as a total for the 48 contiguous states and 10 provinces.

Since ASTRAP has been a research model as well as an assessment model, several algorithms have been changed since the MOI effort. Among the changes are a decrease of the sulfate dry

Table II: Receptor Regions.

Region		lat.	long.
1	Boundary Waters	49.0	93.0
2	Algoma	46.5	84.0
3	Muskoka	45.0	79.5
4	Quebec City	47.0	72.0
5	Southern Nova Scotia	44.0	66.0
6	Northern Vermont/New Hampshire	45.0	72.0
7	Adirondacks	44.0	74.0
8	Western Pennsylvania	41.0	78.0
9	Smokies	35.0	84.0

deposition velocities by a factor of two (Wesely and Shannon, 1984), an increase in plume tracking from 5 to 7 days, inclusion of an orientation term for trajectory endpoint ensembles, gradual leakage to the free troposphere, and a different stochastic representation of precipitation over water, where analyzed values are missing. In addition, the emission inventory is different; this affects even normalized S-R matrices, since source distribution changes. For all results shown here, the National Acid Precipitation Assessment Program SO_x emission inventory for 1980, already gridded on a 100-130 km scale, was used.

Emissions in cells overlapping boundaries were arbitrarily assigned to the source region with the largest fraction of the cell area. Thus, the emission totals for source regions (shown later in Table IX) will deviate somewhat from the actual 1980 emissions of those particular combinations of states and provinces.

Tables III through V give dry deposition of total sulfur per unit emission for meteorological periods of January and July of 1978, January through December of 1980, and January through December of 1981, while Tables VI through VIII give wet deposition of total sulfur per unit emission for the same periods.

Table III: Annual S Dry Deposition in kg/ha/tg Emission from ASTRAP Simulations with Meteorology for January and July 1978.

Source Region	Receptor Region 1	2	3	4	5	6	7	8	9
1	0.00	0.00	0.00	0.07	1.04	0.03	0.00	0.00	0.00
2	0.01	0.10	0.34	4.72	0.72	8.80	0.96	0.07	0.00
3	0.02	0.53	2.60	0.80	0.45	1.09	1.61	0.92	0.01
4	0.73	0.24	0.14	0.10	0.04	0.08	0.08	0.07	0.02
5	0.00	0.01	0.19	0.49	2.03	1.85	2.93	0.48	0.00
6	0.00	0.04	0.33	0.23	0.34	0.45	0.75	4.60	0.06
7	0.00	0.00	0.03	0.11	0.33	0.28	0.36	0.44	1.05
8	0.00	0.00	0.01	0.01	0.02	0.02	0.02	0.07	1.88
9	0.00	0.12	0.21	0.08	0.07	0.12	0.17	0.47	1.05
10	0.12	0.78	0.86	0.24	0.16	0.31	0.43	0.74	0.14
11	0.10	0.07	0.05	0.01	0.01	0.02	0.03	0.05	0.12
12	0.08	0.03	0.02	0.01	0.01	0.01	0.01	0.02	0.03
13	0.04	0.15	0.38	0.34	0.26	0.63	0.49	1.07	0.58

Table IV: Annual S Dry Deposition in kg/ha/tg Emission from ASTRAP Simulations with 1980 Meteorology.

Source Region	Receptor Region 1	2	3	4	5	6	7	8	9
1	0.00	0.00	0.01	0.09	2.04	0.09	0.04	0.00	0.00
2	0.02	0.17	0.51	4.73	0.70	9.36	1.75	0.18	0.01
3	0.03	0.67	2.75	0.74	0.33	0.93	1.52	1.21	0.03
4	0.66	0.21	0.12	0.08	0.04	0.06	0.07	0.06	0.03
5	0.00	0.02	0.17	0.57	1.65	1.75	2.57	0.82	0.01
6	0.00	0.08	0.45	0.28	0.28	0.51	0.83	0.52	0.07
7	0.00	0.02	0.09	0.15	0.28	0.33	0.41	4.59	1.16
8	0.00	0.02	0.04	0.02	0.02	0.03	0.04	0.12	1.74
9	0.03	0.22	0.29	0.09	0.07	0.13	0.19	0.54	1.03
10	0.28	0.96	0.95	0.23	0.13	0.28	0.40	0.75	0.13
11	0.15	0.08	0.06	0.02	0.01	0.02	0.03	0.06	0.13
12	0.09	0.04	0.02	0.01	0.01	0.01	0.01	0.02	0.02
13	0.06	0.20	0.45	0.36	0.24	0.66	0.53	1.13	0.56

Table V: Annual S Dry Deposition in kg/ha/tg Emission for ASTRAP Simulations with 1981 Meteorology.

Source Region	Receptor Region 1	2	3	4	5	6	7	8	9
1	0.00	0.00	0.01	0.10	1.93	0.09	0.04	0.01	0.00
2	0.01	0.15	0.55	4.86	0.57	7.93	1.74	0.17	0.01
3	0.03	0.62	2.97	0.71	0.30	0.83	1.35	1.17	0.03
4	0.59	0.17	0.10	0.06	0.03	0.05	0.06	0.05	0.02
5	0.00	0.02	0.21	0.67	1.41	2.03	2.74	0.87	0.00
6	0.00	0.10	0.56	0.32	0.28	0.53	0.86	4.42	0.06
7	0.00	0.02	0.10	0.18	0.28	0.39	0.49	0.64	1.11
8	0.00	0.02	0.05	0.02	0.02	0.03	0.05	0.13	1.76
9	0.03	0.25	0.31	0.10	0.08	0.14	0.20	0.55	0.90
10	0.28	1.00	0.92	0.22	0.12	0.26	0.36	0.64	0.13
11	0.16	0.09	0.07	0.02	0.01	0.03	0.04	0.07	0.14
12	0.10	0.04	0.02	0.01	0.00	0.01	0.01	0.02	0.02
13	0.06	0.21	0.50	0.38	0.22	0.62	0.53	1.11	0.52

There is no dominant pattern in the differences among the matrices, save that 1980 and 1981 are more similar to each other than either is to January and July of 1978. (Part of the difference in the 1978 results may be due to a different precipitation analysis method for January 1978 than for all other periods.) As an illustration of the potential importance of quantifying meteorologically induced variability in S-R matrices, a policy analyst might conclude from Table VI that emission control in source region 5 (New England and New York) is six times as effective per unit emission in reducing wet sulfur deposition in the Adirondacks (receptor region 7) as emission control in source region 9 (IN, IL, MO, KY, and TN), while either Table VII or Table VIII indicates that controls in the Northeast would be only three times as effective.

The deposition of individual source regions 1 through 12 is seen to be more variable than the deposition of all sources combined (source region 13). Wet deposition exhibits more

Table VI: Annual S Wet Deposition in kg/Ha/tg Emission from ASTRAP Simulations with Meteorology for January and July 1978.

Source Region	Receptor Region 1	2	3	4	5	6	7	8	9
1	0.00	0.01	0.01	0.11	0.37	0.07	0.03	0.01	0.00
2	0.01	0.14	0.43	2.61	0.75	2.83	0.95	0.19	0.00
3	0.04	0.88	1.97	1.07	0.48	1.11	1.32	0.91	0.04
4	0.46	0.20	0.14	0.14	0.04	0.09	0.09	0.06	0.02
5	0.00	0.09	0.35	1.01	0.99	1.69	2.16	0.45	0.00
6	0.01	0.23	0.79	0.62	0.41	0.74	0.91	3.31	0.07
7	0.00	0.03	0.21	0.52	0.40	0.78	0.99	1.08	0.47
8	0.00	0.03	0.09	0.03	0.03	0.05	0.08	0.39	3.55
9	0.05	0.33	0.45	0.22	0.11	0.27	0.36	0.73	1.15
10	0.28	1.10	0.79	0.31	0.13	0.33	0.43	0.62	0.19
11	0.25	0.25	0.20	0.08	0.03	0.08	0.11	0.16	0.19
12	0.13	0.05	0.03	0.01	0.00	0.01	0.01	0.01	0.02
13	0.07	0.29	0.51	0.44	0.24	0.52	0.56	0.99	0.79

Table VII: Annual S Wet Deposition in kg/ha/tg Emission from ASTRAP Simulations with 1980 Meteorology

Source Region	Receptor Region 1	2	3	4	5	6	7	8	9
1	0.00	0.01	0.03	0.23	1.33	0.17	0.09	0.02	0.00
2	0.04	0.26	0.59	2.25	0.72	3.77	1.14	0.19	0.02
3	0.09	0.79	3.93	0.93	0.57	1.12	1.53	1.19	0.06
4	0.61	0.31	0.20	0.15	0.08	0.13	0.13	0.10	0.05
5	0.01	0.09	0.28	0.67	1.46	1.20	1.43	0.60	0.01
6	0.03	0.23	0.50	0.53	0.72	0.74	0.86	2.77	0.12
7	0.01	0.09	0.22	0.35	0.63	0.51	0.52	0.46	0.42
8	0.02	0.09	0.16	0.11	0.13	0.16	0.21	0.37	1.89
9	0.10	0.33	0.46	0.30	0.30	0.38	0.45	0.77	1.08
10	0.30	0.81	0.86	0.45	0.32	0.49	0.59	0.88	0.22
11	0.21	0.24	0.22	0.10	0.07	0.12	0.15	0.23	0.29
12	0.14	0.08	0.05	0.03	0.02	0.03	0.03	0.04	0.04
13	0.10	0.29	0.63	0.42	0.42	0.58	0.57	0.92	0.57

Table VIII: Annual S Wet Deposition in kg/ha/tg Emission from ASTRAP Simulations with 1981 Meteorology

Source Region	Receptor Region 1	2	3	4	5	6	7	8	9
1	0.00	0.01	0.02	0.23	1.91	0.17	0.08	0.02	0.00
2	0.02	0.27	0.74	2.42	0.70	3.67	1.69	0.21	0.01
3	0.06	0.89	3.36	0.84	0.50	0.93	1.24	1.10	0.02
4	0.43	0.22	0.16	0.11	0.06	0.10	0.10	0.09	0.04
5	0.00	0.05	0.27	0.76	1.41	1.38	1.68	0.58	0.00
6	0.02	0.19	0.71	0.69	0.73	0.90	1.07	3.13	0.05
7	0.01	0.07	0.23	0.46	0.69	0.67	0.70	0.59	0.38
8	0.02	0.11	0.21	0.16	0.18	0.22	0.27	0.43	1.96
9	0.10	0.41	0.60	0.39	0.35	0.49	0.58	0.83	0.78
10	0.28	0.83	0.88	0.45	0.30	0.48	0.56	0.74	0.13
11	0.23	0.27	0.23	0.11	0.07	0.12	0.15	0.23	0.28
12	0.12	0.07	0.05	0.02	0.01	0.02	0.03	0.04	0.03
13	0.09	0.30	0.66	0.48	0.44	0.64	0.66	0.99	0.49

variability than dry deposition, although the variability of dry deposition of individual source regions is quite noticeable.

A further illustration of the potential uncertainty in extending the results of too brief a period of simulation is shown in Table IX, in which calculations of the absolute contribution to anthropogenic sulfur wet deposition in the Adirondacks produced by different two-month combinations of 1981 meteorology (with seasonal emission fields, but all scaled to the same annual totals) are given. Table X provides the corresponding percentage contributions. Absolute deposition is more variable than relative deposition; note that the estimates of wet sulfur deposition from all sources varies by more than a factor of two. The ratios of the contributions of any two source regions show wide ranges in these two-month simulations.

Table IX: Annual Wet Deposition of Anthropogenic Sulfur in the Adirondacks in kg/ha as Estimated with Various Two-Month Periods of 1981 Meteorology.

Source	Emissions	Meteorological Period					
Region	(tg S)	Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
1	0.23	0.00	0.02	0.02	0.01	0.02	0.02
2	0.57	0.95	0.59	1.18	0.76	1.76	0.59
3	1.07	1.10	1.37	1.27	1.03	1.34	1.65
4	0.25	0.02	0.03	0.05	0.03	0.01	0.02
5	0.56	0.59	1.01	1.06	0.35	2.34	0.55
6	2.50	1.82	4.10	2.23	1.38	4.21	1.42
7	0.87	0.31	0.74	0.49	0.13	1.80	0.23
8	1.88	0.13	0.53	0.39	0.84	1.00	0.20
9	3.28	1.22	2.81	0.99	1.62	2.08	1.97
10	1.04	0.45	0.80	0.50	0.44	0.40	0.81
11	0.82	0.06	0.07	0.09	0.20	0.19	0.18
12	1.59	0.03	0.04	0.05	0.08	0.01	0.05
13	14.67	6.67	12.11	8.33	6.88	15.15	7.68

Table X: Percentage Contributions to Annual Wet Deposition of Anthropogenic Sulfur in the Adirondacks for Simulations with Various Two-Month Periods of 1981 Meteorology

Source		Meteorological Period					
Region	Emissions	Jan/Jul	Feb/Aug	Mar/Sep	Apr/Oct	May/Nov	Jun/Dec
1	1.6	0.1	0.2	0.2	0.1	0.1	0.2
2	3.9	14.2	4.9	14.2	11.0	11.6	7.7
3	7.3	16.5	11.3	15.2	15.0	8.8	21.5
4	1.7	0.3	0.2	0.6	0.4	0.1	0.2
5	3.8	8.8	8.3	12.7	5.1	15.4	7.2
6	17.0	27.3	33.9	26.8	20.1	27.8	18.5
7	5.9	4.6	6.1	5.9	1.9	11.9	3.0
8	12.8	1.9	4.4	4.7	12.2	6.6	2.6
9	22.4	18.2	23.2	11.9	23.5	13.7	25.7
10	7.1	6.7	6.7	6.0	6.4	2.6	10.5
11	5.6	0.8	0.6	1.1	2.9	1.2	2.3
12	10.8	0.4	0.5	0.6	1.1	0.1	0.7

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